IMAGE SENSOR HAVING MICRO-LENS ARRAY SEPARATED WITH RIDGE STRUCTURES AND METHOD OF MAKING

TECHNICAL FIELD

[0001] The present invention relates to image sensors, and more particularly, towards an image sensor that has a micro-lens array that is separated by ridges.

BACKGROUND

[0002] Image sensors are electronic integrated circuits that can be used to produce still or video images. Solid state image sensors can be either of the charge coupled device (CCD) type or the complimentary metal oxide semiconductor (CMOS) type. In either type of image sensor, a light gathering pixel is formed in a substrate and arranged in a two-dimensional array. Modern image sensors typically contain millions of pixels to provide a high-resolution image. An important part of the image sensor are the color filters and micro-lens structures formed atop of the pixels. The color filters, as the name implies, are operative, in conjunction with signal processing, to provide a color image. Examples of color filter technology are shown in U.S. Patent No. 6,297,071 and U.S. Patent No. 6,274,917 (and the references cited therein). The micro-lenses serve to focus the incident light onto the pixels, and thus to improve the fill factor of each pixel.

[0003] Conventionally, micro-lenses are formed by spin coating a layer of micro-lens material onto a planarized layer. The micro-lens material is then etched to form cylindrical

or other shaped regions that are centered above each pixel. Then, the micro-lens material is heated and reflowed to form a convex hemispherical micro-lens. Figure 1 shows a prior art cross-sectional simplified diagram of an image sensor 101 having micro-lenses formed thereon. As seen in Figure 1, the image sensor includes a plurality of pixels that have light detecting elements 103 formed in the substrate. The light detecting elements 103 may be one of several types, such as a photodiode, a photogate, or other solid state light sensitive element. Formed atop of each pixel is a micro-lens 105. The micro-lens 105 focuses incident light onto the light detecting elements 103. Moreover, in the region between the light detecting elements 103 and the micro-lens 105, denoted by reference numeral 107, there are various intervening layers that would typically include the color filter layers and various metal conducting lines.

[0004] The formation of the micro-lenses is a relatively precise process. In order to increase the efficiency of the light gathering aspect of the micro-lenses, the micro-lenses should be as large as possible. Still, it is undesirable for the individual micro-lenses to contact each other and thereby interfere. In sum, it is desired that the micro-lenses be as close to each other as possible with touching.

[0005] While this may be accomplished by precisely controlling the formation, size, and shape of the microlens cylindrical "blank", as well as by controlling the reflow process, it is still difficult to ensure the formation of nearly perfect micro-lenses.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Figure 1 is a prior art cross sectional view of a portion of an image sensor.

[0007] Figure 2 is a top view of an image sensor showing pixels arranged in a two-dimensional array and with micro-lenses formed thereon.

[0008] Figures 3-4 and 6-8 are cross sectional views of a semiconductor substrate illustrating one method for forming the apparatus of the present invention.

[0009] Figure 5 is a top view of circular triangular ridges formed over pixels of an image sensor.

DETAILED DESCRIPTION

[0010] The present invention relates to a micro-lens array for use with image sensors, either of the CMOS or CCD type. In the following description, numerous specific details are provided to provide a thorough understanding of the embodiments of the invention. One skilled in the relevant art will recognize, however, that the invention can be practiced without one or more of the specific details, or with other methods, components, etc. In other instances, well-known structures or operations are not shown or described in detail to avoid obscuring aspects of various embodiments of the invention.

[0011] Reference throughout the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the present invention. Thus, the appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout the specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

[0012] Figure 2 shows a top view of an image sensor 201 formed in accordance with the present invention. The image sensor 201 includes a plurality of pixels 203 typically arranged in a two dimensional array. In the example shown in Figure 2, the image sensor shows a three by three array of pixels 203, though it can be appreciated that an actual mage sensor 201 would have many more pixels, arranged in perhaps over a thousand rows and/or a thousand columns. Further, although Figure 2 shows the pixels in ordered columns and rows, the pixels may be arranged in any type of ordered arrangement. For example, alternating rows may have their pixels slightly offset from each other laterally in a checkerboard format.

[0013] The pixels 203 typically include a light sensitive element, such as a photodiode or a photogate as two examples. However, it can be appreciated that other types of light sensitive elements, now known or developed in the future, may be used. Further, the pixels 203 will also include amplification and/or readout circuitry. For clarity, this circuitry is not shown in Figure 2. In one embodiment, the pixels 203 may be active pixels, commonly known in the prior art. Formed atop of each pixel 203 is a micro-lens 205. Further, separating the individual micro-lenses is a ridge structure 207. As the name implies, the ridge structure 207 is a raised area that serves as a wall separating the micro-lenses. As will be seen in greater detail below, the micro-lenses 205 are prevented from "overflowing" (during the reflow process) to the neighboring micro-lenses by the ridge structure 207. The ridge structure 207 may take a variety of shapes, but should serve to separate neighboring pixels.

[0014] Figures 3-7 show in greater detail the formation and structure of the combination micro-lenses 205 and ridge structure 207 of the present invention. A semiconductor

substrate 301 has a plurality of light sensitive elements 303 (associated with the pixels 203 of Figure 2) formed therein. Figure 3 shows the light sensitive element 303 as a photodiode, though other substitutes and equivalents may be used. Details of forming the photodiode and other associated circuitry are known in the prior art and will not be repeated herein to avoid obscuring the present invention. However, examples of the prior art may be seen in U.S. Patent No. 5,904,493 and U.S. Patent No. 6,320,617.

[0015] Formed atop of the light sensitive elements 303 are color filters. In accordance with one embodiment of the present invention, a planar color filter layer 401 is deposited over the substrate 301 and light sensitive elements 303. It should be noted that while in this particular embodiment, the color filter layer 401 is formed directly over the substrate 301, in other embodiments, the color filter layer 401 is formed over an intermediate layer or layers, depending upon the particular process used. For example, in some instances, a planarizing dielectric layer is formed over the substrate, or in other instances, conductive metal layers and insulating layers are formed over the substrate.

[0016] The color filter layer 401 is composed of three separate color layers that have been patterned and etched to form the color filter layer 401. In one embodiment, the color filter layer 401 includes red, green, and blue colors. In another embodiment, the color filter layer 401 includes yellow, cyan, and magenta colors. The color filter layer 401 is formed from a pigmented or dyed material that will only allow a narrow band of light to pass therethrough, for example, red, blue, or green. In other embodiments, the color filter may be cyan, yellow, or magenta. These are but example colors for the color filter layer 401 and the present invention is meant to encompass a color filter layer 401 having any combination of color.

[0017] Further, while the use of pigmented or dyed color materials is the most prevalent form of color filters, other reflective type color filters may be used, such as a multilayer stack reflective material. The formation of color filter layer 401 is known in art and will not be described herein to avoid any unnecessary obscuration with the description of the present invention. For example, U.S. Patent No. 6,297,071, U.S. Patent No. 6,362,513, and U.S. Patent No. 6,271,900 show the current state of the color filter art.

[0018] Typically, the color filter layer 401 is formed from a material such as an acrylic. For example, a suitable material is polymethylmethacrylate (PMMA) or polyglycidylmethacrylate (PGMA) that has been pigmented or dyed. Other photoresist-type materials that can be dyed or pigmented may also be used for the color filter layer 401.

[0019] Still referring to Figure 3, a top planarizing layer 403 is formed. The top planarizing layer 401 is formed from a dielectric material, such as an oxide formed by a blanket chemical vapor deposition process.

[0020] Turning to Figure 4, a photoresist layer is deposited over the top planarizing layer 403 and patterned to leave photoresist ridges 405. The photoresist ridges 405 are placed in locations such that the pattern formed by the photoresist ridges 405 serves to separate neighboring underlying pixels. Therefore, the photoresist ridges 405 should act as a fence for the individual micro-lens to be formed. In some embodiments, the photoresist ridges 405 should be formed as a quadrilateral (such as that shown in Figure 2), or in other embodiments, be formed as a circle, so as to more clearly define the micro-lens shape. Other shapes are also possible.

[0021] Figure 5 shows a top view of the photoresist ridges 405 if formed in a circular shape. As seen in Figure 5, the photoresist ridges 405 form a plurality of circular rings that will serve to contain a subsequently formed micro-lens.

[0022] In one embodiment, the photoresist ridges 405 have a width of about 0.3-0.5 microns, though thinner structures can be used. Further, the height of the photoresist ridges 405 may vary widely, but in one embodiment may be on the order of 1 micron in height.

[0023] Further, one example of a suitable photoresist material is Tokyo Ohka Kogyo's OFPR-800 positive photoresist. The photoresist may be coated onto the top planarizing layer 403 by means of a spin on technique. It can be appreciated that other photoresists may be used, such as an i-line photoresist. The photoresist layer is then patterned using conventional photolithography and development techniques, such as for example using an i-line stepper.

[0024] Next, turning to Figure 6, in one embodiment an isotropic dry etching (etching in both the x and y directions) process is performed on the top planarizing layer 403 and the photoresist ridges 405. Because of the isotropic etching technique, the photoresist ridges 405 are etched away, as well as the uncovered portions of the top planarizing layer 403. Additionally, those portions of the top planarizing layer 403 that underly the photoresist ridges 405 are etched to form triangular ridges 601. In one embodiment, the isotropic etching process is controlled such that the height of the triangular ridges 601 is on the order of 0.2 microns. Further, in one embodiment, the isotropic etching has a substantially equal etching rate in the x and y directions. Note that the shape of the triangular ridges 601 results from the isotropic etching. If anisotropic etching is used the ridges 601 would be of the same shape as the photoresist ridges 405.

[0025] Next, turning to Figure 7, a micro-lens material is formed over the top planarizing layer 403 and the triangular ridges 601. The micro-lens material may be any material that is optically transparent and subject to formation into a hemispherical shape by processes. For example, some common micro-lens material may be an acrylic, such as polymethylmethacrylate (PMMA) or polyglycidylmethacrylate (PGMA). However, it can be appreciated that the precise material used to form the micro-lenses is variable, and may be any currently used or future material.

[0026] In one embodiment, the micro-lens material may be a material in liquid state during application such that it can be applied using spin on techniques. This provides the advantage of forming a substantially planar layer. Nevertheless, other blanket deposition methods may also be suitable. In one embodiment, the thickness of the micro-lens material is on the order of 1 to 4 microns. However, thinner or thicker layers of the micro-lens material may also be used, depending on various design parameters.

[0027] Still referring to Figure 7, the micro-lens layer will need to be patterned. Because of this, it is efficient to use a photoresist type material as the micro-lens material. In that way, the micro-lens material can be "directly patterned" by simply the use of a photolithography apparatus and a developing process. In one embodiment, the photolithography is performed by a reduction type stepper apparatus.

[0028] Where the micro-lens material is a photoresist, the micro-lens material is exposed using a reticle mask and stepper apparatus. The reticle mask is designed such that gap sections 703 are exposed to the photolithographic radiation (in the case of a positive photoresist). Thus, when developed, gap sections 703 will be removed, leaving blocks of

micro-lens material 701, generally over the light detecting elements and between the triangular ridges 601.

[0029] Turning to Figure 8, once the micro-lens material has been developed (in the case of the micro-lens material being a photoresist), the remaining portions of the micro-lens material 701 are heated to a reflow temperature. This causes the micro-lens material 701 to adopt a minimum surface tension shape, which results in a spherical shape, as shown in Figure 8. As seen in Figure 8, the individual micro-lens are confined by the triangular ridges after the reflow process.

[0030] Using the structure and method described herein, the amount of crosstalk between adjacent micro-lens structures is reduced as a result of the triangular ridges 601. Further, because of the triangular ridges 601, there is a greater process margin during the micro-lens formation process. Moreover, the use of the separating ridges reduces the gaps between micro-lenses, increases the precision of the micro-lens placement, and provided other advantages.

[0031] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims. Thus, while these steps are shown in a particular order, in some embodiments these steps are re-arranged, and some steps may be deleted, moved, added, subdivided, combined, and/or modified. Each of these steps may be implemented in a variety of different ways. Also, while these steps are shown as being performed in series, these steps may instead be performed in parallel, or may be performed at different times.